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THE THERMAL RESPONSE OF
HEAT-SINK REENTRY VEHICLES

by

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POLYTECHNIC INSTITUTE OF BROOKLYN

DEPARTMENT OF
AERONAUTICAL ENGINEERING AND APPLIED MECHANICS

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1. Introduction

In a performance comparison of reentry vehicles there are a number of important interrelated criteria determining the acceptability of the vehicle. These include the peak deceleration, the limits imposed by atmospheric heating, guidance control and accuracy, and time of descent. A general study has been undertaken which places emphasis on the first two considerations and is based on three vehicle configurations appropriate to both manned and unmanned entry into the earth's atmosphere from high supercircular speeds. The first vehicle type, designated "sphere" is a high drag, nonlifting body. The second, referred to below as the "body" type, is of moderate drag and possesses a trimming lift capability; while the third, the "wing", simulates low-drag, high lift vehicles. For each configurational type heat transfer behavior is to be assessed on the basis of three techniques of heat dissipation, viz., by radiation alone, by ablation or internal cooling, and by the utilization of the vehicle as a heat sink.

In this paper are presented the results of the heat sink studies in the form of thermal-time response and specifically in terms of temperature-time histories and peak temperatures as a function of vehicle mass, shape and aerodynamic parameters, entry orbit. The thermal response is correlated to peak deceleration.

The nose of each vehicle can be thought of as spherical and is defined by the nose radius R' and the wall thickness D . If R' and D are within certain bounds, the differential equation governing the temperature of the nose is essentially one-dimensional. The heat balance is dependent on the velocity and altitude of the vehicle at all times. These are known from earlier trajectory computations. For a representative range of single and multipass entry orbits there are presented peak temperature contours in the R' - D plane which permit a choice of R' , D combinations which for a given peak deceleration place limits on temperature.

In determining material constants appearing in the differential equation the heat shield is assumed to be manufactured of a so-called high performance material such as beryllium oxide ($T_{\max} = 5125^{\circ}\text{R}$).

2. Notation

| | |
|-------|---|
| A' | = 25,688 |
| B' | = 1349.2 |
| C_0 | = -7.348; $C_1 = .10842$; $C_2 = -3.1476 \cdot 10^{-5}$ |
| C_3 | = 56.25; $C_4 = .0175$ |
| D | = 0.01 - 0.05 feet; thickness parameter, variable |
| E' | = $0.21625 \cdot 10^{-12}$. $T_s^4 = .055303$ (BTU/ft ² sec) |
| e | eccentricity of ex-atmospheric ellipse |
| h | time step used in temperature calculations. (sec) |
| h' | time step used in trajectory calculations. (sec)($h=h'/N$) |
| k | = $0.11856 \cdot 10^9$ ft. ^{3/2} sec ⁻¹ . |
| N | = h'/h |
| R' | = 2 ft. - 12 ft.; variable vehicle parameter. |
| R | radial distance from the earth's center; non-dimensionalized with respect to r_a . |
| R_0 | = .96957 = radius of spherical earth |
| r_a | = $2.1556 \cdot 10^7$ feet; radius of the initial condition (200 km.) |
| S | = 2 cal/min. cm. ² = .1229 BTU/sec.ft. ² ; solar constant |
| t' | = $t'(\theta)$ time in seconds in an elliptical orbit, measured from the line of apses. |
| t'' | = $t''(T)$ time in seconds (see "Multiple Pass Trajectories"). |
| T_w | = T/T_s ; non-dimensionalized wall temperature of vehicle. |
| T | absolute wall temperature of vehicle. |
| T_s | = $711.13^{\circ}\text{R} = (\alpha S/E')^{1/4}$ equilibrium temperature of the vehicle outside the atmosphere. |

| | |
|----------------|---|
| V | non-dimensional velocity = v/v_0 |
| V_0 | initial velocity V at 200 km. altitude for which $R=1$. |
| v | absolute velocity (ft./sec.). |
| v_0 | 25,546 ft./sec.; circular orbital velocity at 200 km. altitude. |
| v_s | = 26,000 ft./sec.; normalizing factor for velocity used in temperature analysis. |
| y | altitude above sea-level (feet). |
| y_e | = $0.65595 \cdot 10^6$ ft.; initial altitude (200 km.). |
| $\bar{\alpha}$ | = 0.45; vehicle coefficient of absorptivity. |
| α | angle of incidence |
| β | = $1/22,000 = .45455 \cdot 10^{-4}$ ft. ⁻¹ scale height of the atmosphere. |
| τ | = period of elliptical orbit |
| w | angular coordinate; true anomaly in Keplerian ellipse. |
| γ | flight path angle, positive upwards |
| γ_0 | initial value of γ . |

3. The Heat Transfer Equation

The one-dimensional differential equation governing the non-dimensional wall temperature T_w of the vehicle is:

$$\frac{dT_w}{dt} = \left\{ \frac{A'}{(R')^{1/2}} \left(\frac{v}{v_s} \right)^{13/4} [1 - 0.3 T_w/h_{se}] e^{-\beta y/2} - E' T_w^4 + \bar{\alpha} S \right\} \frac{1}{C(T_w)D}$$

This states that the heat transfer is a balance of forced convection heating (aerodynamic effects), thermal radiation (according to Planck's law) and solar irradiation. The source of the first term in this equation is Ref. (1), and it is seen to include the influence of surface temperature on the convective heating rate. A value of the solar constant S was found in Ref. (2). Other numerical data are listed in the Notation.

The coefficients of the differential equation depend on the time history of velocity v and altitude y ; and can be computed

from pre-calculated trajectories given in the form of V , R (nondimensional velocity, radial distance) pairs at discrete time intervals.

4. The Numerical Integration

The temperature equation can be integrated numerically by a Runge-Kutta technique (Ref. 3). In the procedure, an equation of the type $dT/dt = f(t, T)$ is integrated using the well-known formulas:

$$T(t+h) = T(t) + 1/6(k_1 + 2k_2 + 2k_3 + k_4) ,$$

$$k_1 = hf(t, T); \quad k_2 = hf(t+h/2, T+k_1/2) ,$$

$$k_3 = hf(t+h/2, T+k_2/2); \quad k_4 = hf(t+h, T+k_3).$$

The time step h must be chosen sufficiently small. The permissible value is determined by successively decreasing h until results become insensitive to variations in h .

In the present problem, the velocities V and altitudes y (or R) which determine $f(t, T)$, are tabulated at time intervals h' . The time interval used in the trajectory calculations, h' , usually varies considerably during any given trajectory (Ref. 4). In the temperature calculations, the time step h was determined from the given time step h' by the relation $h = h'/N$, N being an integer. Thus for $N=1$, the temperature is calculated at the same time intervals as the given velocity and altitude. The corresponding velocity and altitude are interpolated linearly between any two values. It was found by comparative calculations that parabolic or higher order interpolation between the table values was unnecessary.

The Runge-Kutta process was programmed for a Bendix G15 Computer, so that there are printed out six quantities for each integration step in the following order: (t) time in seconds; (T_w) wall temperature nondimensionalized with respect to $T_s = 711.13^\circ R$; (T) temperature in $^\circ R$; (V) given nondimensionalized

velocity; (R) given nondimensionalized distance from the earth's center; $(dT/dt) = f(t, T)$ rate of change of nondimensionalized temperature. The time required to compute one temperature is approximately 50 seconds.

Comparative results indicate that the time step, h , used in the temperature calculations can be chosen equal to the given time step, h' , of the trajectory calculations which is related to the acceleration magnitude; i.e., $N=1$ is acceptable. The initial temperature of the vehicle, which must be prescribed, can be varied by as much as 10% without noticeably influencing the ensuing temperature history. The initial temperature (i.e., the temperature $T_s = (2S/E')^{1/4}$ of a body in free space for which thermal equilibrium exists between solar irradiation and thermal reradiation) for all atmospheric passes was therefore fixed at $T_s = 711.13^\circ\text{R}$.

5. Initial Conditions and Input Data

Initial Temperature:

For all calculations the chosen initial temperature was 711.13°R , which is based on an absorptivity $\bar{\alpha} = 0.45$.

Time step:

The chosen time step was the one used in the trajectory calculations; this varied continuously⁽⁴⁾ from 50 seconds prior to actual entry, through 5-10 seconds near entry, to a minimum of 2.5 seconds when decelerations are greatest.

R' (nose radius) - D (thickness):

Each trajectory was run for several R' and D combinations in the range $2 < R' < 6$ and $.01 < D < .05$ ft. The combinations were chosen so as to delineate a peak temperature contour in the $R' - D$ plane of close to 5125°R , the acceptable limit for a material such as beryllium oxide.

"Sphere" - trajectories:

These trajectories carry the notation "S". All trajectories begin outside the effective limit of the earth's atmos-

where, i.e., at an initial value $R=1$. Two initial super-circular velocities were considered: $V=1.3911$ and $V=1.3088$. This group includes nine single-pass trajectories, two double-pass, one triple-pass and one quadruple pass trajectory defined by a range of entry-angles.

"Body" - trajectories:

These trajectories carry the notation "B". These also have an initial $R=1$, and an initial velocity $V=1.3911$. This group is composed of fifteen trajectories including three skip trajectories of which nine lead to impact upon the first pass.

"Wing" - trajectories:

No temperature calculations have been made so far.

6. Multiple Pass Trajectories

In order to cater for multiple-pass trajectories, the machine storage of the given trajectory data V , R , t becomes excessive. It proves unnecessary anyway. Since the convection terms in the differential equation can be neglected outside the atmosphere, the equation can be integrated analytically. The result is:

$$t''(T) = (D/4E'T_s^3) \left\{ (a_0 + a_2 T_s^2) \log_e \left(\frac{T_w + 1}{T_w - 1} \right) + 2(a_0 - a_2 T_s^2) \tan^{-1}(T) \right. \\ \left. + a_1 T_s \log_e \left(\frac{T_w^2 + 1}{T_w^2 - 1} \right) - t''(1700) \right\},$$

where

$$(a_0, a_1, a_2) = (C_0, C_1, C_2) \quad \text{for} \quad 500^\circ < T < 1700^\circ$$

$$(a_0, a_1, a_2) = (C_3, C_4, 0) \quad \text{for} \quad 1700^\circ > T.$$

The time $t'(\omega)$ along an elliptical orbit of eccentricity e and having a period τ is (Ref. 5):

$$t' = \tau \frac{(1-e^2)^{1/2}}{2\pi} \left\{ \frac{-e \sin \omega}{1+e \cos \omega} + \frac{2}{(1-e^2)^{1/2}} \tan^{-1} \left[\frac{(1-e^2)^{1/2}}{(1+e)} \tan(\omega/2) \right] \right\}$$

It is not possible to give an explicit relationship for the temperature in terms of exit angle. A plot of both $t'(\omega)$ and $t''(T)$ (for $D=.02$) is given with which it is possible to determine the temperature of the vehicle at entry into the atmosphere at the end of an elliptical pass in free space. The information required for this is the temperature at exit, (i.e., at the beginning of the elliptical path) the eccentricity and the period of revolution of the ellipse. See Figs. 1, 2 and 3 and the Appendix.

A study of these graphs shows that for all practical purposes, the satellite vehicle cools off to essentially the equilibrium temperature, $T_s = 711.13^\circ R$, during its flight along the ellipse, irrespective of the temperature it had at the beginning of the ellipse. However, for flight times outside the atmosphere of less than about 10,000 sec. (for $D=.02$) the temperature at reentry can be considerably higher than $711.13^\circ R$.

7. Presentation of Results

Two forms of graphical presentation are given. The first (Figs. 4-10) consists of wall temperature-time histories and is designed to illustrate the typical effects of entry with and without lift, of initial velocity (V_0) and entry angle (γ_0), and of the loading ratio $C_D \bar{S}/m$. Temperature effects are related to trajectory type and the acceleration-time history or the peak deceleration. Figure 5 relates the heat transfer (dT/dt) to temperature.

The second set of curves (Figs. 11-18) depicts the influence of vehicle nose radius (R') and skin thickness (D) on peak temperature for a variety of initial velocities, entry angles, $C_D \bar{S}/m$ ratios, and angles of incidence. Contours of constant peak wall temperature are given in the $R'-D$ plane. These were obtained by linear interpolation of peak temperatures at points of a mesh, some of which are shown in addition to the interpolated contours.

Some essential properties of the trajectories used for the heat transfer computations are summarized in Table I for the nonlifting vehicle and in Table II for the "body" with trimming lift capability. The latter is defined by the coupled lift-drag laws

$$C_L = M\alpha$$

$$C_D = C_{D_0} + Q\alpha^2$$

where $M = \partial C_L / \partial \alpha$, C_{D_0} , Q are varied constants and α is the angle of incidence with $\alpha_{\max} = 30^\circ$.

NONLIFTING VEHICLE ENTRY ($\alpha=0$) FROM 200 Km.

| INITIAL VELOCITY V_o | ENTRY ANGLE $-\gamma_o$ | LOADING ($\frac{m}{C_D S}$) | ABSOLUTE ACCELERATION $A_{\max.}$ | TERMINAL CONDITION | SEE FIGURES |
|------------------------------|-------------------------------|----------------------------------|---|-----------------------|----------------|
| 1.3911 | 8° | 100 lb/ft ² | 1.3g | exit | 5, 11 |
| | $8-1/4$ | 100 | 2.8 | exit | 11 |
| | $8-1/2$ | 100 | 7.6; 7.0 | impact | 11 |
| | 9 | 100 | 18.1 | impact | 5, 11 |
| 1.3911 | 8 | 25 | 3.4; 8.6 | impact | 4, 12 |
| | $8-1/4$ | 25 | 8.0 | impact | 4, 12 |
| | $8-1/2$ | 25 | 13.6 | impact | 4, 12 |
| 1.3088 | $7-1/2$ | 100 | 1.3 | exit | 15 |
| | 8 | 100 | 8.9 | impact | 5, 15 |
| | 9 | 100 | 23.6 | impact | 5, 15 |
| 1.3088 | 7 | 25 | 1.02 | exit | 16 |
| | $7-1/2$ | 25 | 3.3; 7.7 | impact | 16 |
| | 8 | 25 | 13.5 | impact | 16 |

TABLE I "S" Trajectories

LIFTING VEHICLE ENTRY ($V_0 = 1.3911$) FROM 200 km.

| INCI- DENCE ANGLE α | ENTRY ANGLE $-\gamma_0$ | LOADING ($\frac{m}{s}$) | DRAG at $\alpha=0$ C_{D_0} | LIFT SLOPE $\frac{\partial C_L}{\partial \alpha}$ | LIFT DRAG $(\frac{C_L}{C_D})_{max}$ | RELATIVE ACCELER- ATION \bar{A}_{max} | TERMINAL CONDI- TION | SEE FIGURES |
|-------------------------------------|-------------------------------|----------------------------------|---------------------------------------|---|---|--|----------------------------|----------------|
| 0 | 8° | 25 lb/ft ² | 0.6 | 0.01 | 1 | 2.0g | exit | 6,8,13 |
| | 9 | 25 | 0.6 | 0.01 | 1 | 20.3 | impact | 6,7,13 |
| | 12 | 25 | 0.6 | 0.01 | 1 | 53.8 | impact | 6,13 |
| | 8 | 50 | 0.4 | 0.02 | 0.5 | 0.7 | exit | 14 |
| | 9 | 50 | 0.4 | 0.02 | 0.5 | 17.1 | impact | 7,14 |
| | 9 | 50 | 0.6 | 0.01 | 1 | 18.3 | impact | 7,14 |
| | 9 | 25 | 0.4 | 0.02 | 0.5 | 19.1 | impact | 7,14 |
| 5° | 8 | 25 | 0.6 | 0.01 | 1 | 1.8 | exit | 8,17 |
| | 9 | 25 | 0.6 | 0.01 | 1 | 15.0 | impact | 17 |
| 10° | 8 | 25 | 0.6 | 0.01 | 1 | 1.6 | exit | 8,17 |
| | 9 | 25 | 0.6 | 0.01 | 1 | 12.2;5.1 | impact | 17 |
| 30° | 8 | 25 | 0.6 | 0.01 | 1 | 1.6 | exit | 8,9,18 |
| | 9 | 25 | 0.6 | 0.01 | 1 | 8.7 | exit | 9,18 |
| | 10 | 25 | 0.6 | 0.01 | 1 | 17.0;8.6; 3.4;1.2 | impact | 9,10,18 |
| | 12 | 25 | 0.6 | 0.01 | 1 | 31.0;1.8; 1.1 | impact | 9,18 |

TABLE II "B" Trajectories

A complete set of peak temperatures is given by Tables IV through XII. These formed the basis of the contours of Figs. 4 through 18.

8. Temperature-Time Histories

Entry without lift:

Figure 4. The effect of entry angle on trajectory (R), absolute wall temperature (T), absolute acceleration.

$V_o = 1.3911$, $C_D \bar{S}/m = 0.04$, $\alpha = 0$, $R' = 4$, $D = 0.01$.

Figure 5. The effect of initial velocity on trajectory (R), absolute wall temperature (T), absolute acceleration.

$-\gamma_o = 8^\circ$ and 9° , $C_D \bar{S}/m = 0.01$, $\alpha = 0$, $R' = 6$, $D = 0.04$.

Figure 6. The alleviating effect of steep entry on peak wall temperature. $V_o = 1.3911$, $C_D \bar{S}/m = 0.024$, $\alpha = 0$, $R' = 4$, $D = 0.03$.

Figure 7. The effect of aerodynamic loading, $C_D \bar{S}/m$.
 $V_o = 1.3911$, $-\gamma_o = 9^\circ$, $\alpha = 0$, $R' = 6$, $D = 0.05$.

Entry with lift:

Figure 8. The effect of constant lift on wall temperature.

$V_o = 1.3911$, $-\gamma_o = 8^\circ$, $m/\bar{S} = 25 \text{ lb/ft}^2$, $C_{D_o} = 0.6$, $\partial C_L / \partial \alpha = 0.01$,
 $(C_L/C_D)_{\max} = 0.5$, $R' = 6$, $D = 0.01$.

Figure 9. The effect of entry angle at maximum lift.

$V_o = 1.3911$, $\alpha = 30^\circ$, $m/\bar{S} = 25 \text{ lb/ft}^2$, $C_{D_o} = 0.6$, $\partial C_L / \partial \alpha = 0.01$,
 $(C_L/C_D)_{\max} = 0.5$, $R' = 6$, $D = 0.03$.

Figure 10. Entry at maximum lift; the effect on temperature of nose geometry (R' and D). $V_o = 1.3911$, $\alpha = 30^\circ$,
 $-\gamma_o = 10^\circ$, $m/\bar{S} = 25 \text{ lb/ft}^2$, $C_{D_o} = 0.6$, $\partial C_L / \partial \alpha = 0.01$,
 $(C_L/C_D)_{\max} = 0.5$.

9. The Influence of Nose Geometry on Peak Wall Temperature

Entry without lift:

Figure 11. The effect of entry angle. $V_0 = 1.3911$, $\alpha = 0$, $C_D \bar{S}/m = 0.010$.

Figure 12. The effect of entry angle. $V_0 = 1.3911$, $\alpha = 0$, $C_D \bar{S}/m = 0.040$.

Figure 13. The effect of steep entry. $V_0 = 1.3911$, $\alpha = 0$, $C_D \bar{S}/m = 0.024$.

Figure 14. The effect of aerodynamic loading $C_D \bar{S}/m$. $V_0 = 1.3911$, $\alpha = 0$.

Figure 15. The effect of entry angle. $V_0 = 1.3088$, $\alpha = 0$, $C_D \bar{S}/m = 0.010$.

Figure 16. The effect of entry angle. $V_0 = 1.3088$, $\alpha = 0$, $C_D \bar{S}/m = 0.040$.

Entry with lift:

Figure 17. Low and moderate lift entry. $V_0 = 1.3911$, $\alpha = 5^\circ$ and 10° , $-\gamma_0 = 8^\circ$ and 9° .

Figure 18. Maximum lift entry. $V_0 = 1.3911$, $\alpha = 30^\circ$, $-\gamma_0 = 8, 9, 10, 12^\circ$.

10. Conclusions

- a. Temperature-time histories, and particularly peak temperature, are essentially independent of the entry equilibrium wall temperature for the practical range of entry conditions.
- b. For multiple-pass trajectories the vehicle reaches equilibrium temperature during the ex-atmospheric phase prior to reentry unless the ex-atmospheric trajectory is closely circular near the sensible limit of the atmosphere (100-120 km. altitude).
- c. Whereas with increasing entry angle the maximum deceleration increases rapidly, the peak wall temperature is fairly insensitive to entry angle, and moreover, the peak value rises to a maximum and then decreases.

- d. Lower initial entry velocities at the same entry angle may or may not lower the peak wall temperature and maximum deceleration.
- e. The effect of decreasing the aerodynamic loading $m/C_D \bar{S}$ lowers the peak wall temperature.
- f. The effect of entry with constant lift is to decrease slightly the peak temperature, monotonically with increasing incidence angle. Peak deceleration, however, can be drastically reduced at high incidence.
- g. "Skip" trajectories within the effective atmosphere can occur with or without lift. These are characterized by twin deceleration and temperature peaks (for a nonlifting entry) or by multiple deceleration peaks for a lifting entry. In the latter case there may be fewer temperature peaks than acceleration peaks. In any case subsequent peak values of temperature decrease in magnitude, although intervening temperatures usually remain moderately high. The first deceleration peak may or may not be critical; for nonlifting entry the second peak is often much larger; for lifting entry subsequent deceleration peaks are much smaller than the first for the cases presented here but this is by no means always so.
- h. Peak temperatures are relatively insensitive to the vehicle nose radius by comparison with the effect of skin thickness. The higher peaks occur of course with the smaller thicknesses; but the latter lead to lower exit or impact wall temperatures when heat loss due to reradiation occurs.
- i. The curves of Figures 11-18 suggest that for manned or unmanned entry to impact with acceptable decelerations a practical combination of nose radius (R') and skin thickness (D) exists. For example, for manned entry with peak deceleration close to a 15g limit and peak wall temperature to about 5000°R reasonable R' - D combinations can be found for entry under the conditions given by Figs. 12-14, 16-18.

Of these perhaps the most desirable are Figs. 16 and 18. The former is a non-lifting ("S") entry from $V_0 = 1.3088$ with an 8° entry angle and $C_D \bar{S}/m = 0.040$ while the latter is a "B" entry with maximum lift from $V_0 = 1.3911$ with a 10° entry angle and $C_{D_0} \bar{S}/m = 0.036$.

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APPENDIX

Ex-Atmospheric Temperature Response After Exit

Figures 1, 2 and 3 enable the determination of the time-temperature or the position-temperature relationship of the vehicle during ex-atmospheric motion between exit from and re-entry into the planetary atmosphere.

At exit the following quantities are required:

- e eccentricity
- P nondimensionalized semi-latus rectum, p/r_a
- ω true anomaly
- T^x temperature at exit
- R exit altitude (nondimensionalized)

These quantities fix the ex-atmospheric flight time and so, for a given vehicle, the reentry temperature. To find the latter the following procedure can be used:

- (i) Compute the nondimensional semi-major axis $A = P/(1-e^2)$.
Use Fig. 1 to find τ the period of the ellipse.
- (ii) From Fig. 2 find the nondimensional time of flight $\Delta t'/\tau$ using the exit value of ω together with e .
- (iii) Then $\Delta t' = (\Delta t'/\tau)\tau$.
- (iv) In Fig. 3 locate the time $(\frac{0.02t''}{D} + 1000)$ corresponding to T^x and scale it for wall thickness D and so find t'' .
- (v) To this time add $\Delta t'$. Normalize the resultant time to $D = 0.02$, i.e., recalculate $(0.02t''/D + 1000)$ and read from Fig. 3 the reentry temperature. See also Table III.

| $T[^{\circ}R]$ | $t''(T)$ (sec.) | T | $t''(T)$ (sec.) |
|----------------|-----------------|--------|-----------------|
| 711.13 | $+\infty$ | 1700 | 0 |
| 711.2 | 30,034 | 1710 | - 9.6250 |
| 711.5 | 24,281 | 1725 | - 23.781 |
| 712 | 21,328 | 1750 | - 46.422 |
| 720 | 13,318 | 1800 | - 88.203 |
| 800 | 5604.6 | 1900 | -159.88 |
| 900 | 3331.4 | 2000 | -218.86 |
| 1000 | 2196.4 | 2130 | -281.0 |
| 1100 | 1497.0 | 2200 | -309.08 |
| 1200 | 1024.5 | 2300 | -343.98 |
| 1300 | 688.39 | 2400 | -373.80 |
| 1400 | 440.95 | 2500 | -399.45 |
| 1500 | 254.40 | 3000 | -486.19 |
| 1600 | 111.29 | 3550 | -537.47 |
| 1650 | 52.223 | 4000 | -562.80 |
| 1675 | 25.316 | 4500 | -581.48 |
| 1690 | 9.9375 | 5000 | -594.25 |
| 1700 | 0 | 71,150 | -640.34 |

$D = 0.02$ feet

TABLE III

$$V = 1.3911$$

| $-\gamma_o$ deg. | $C_{D_o} \bar{S}/m$ | R' ft. | D ft. | $(\frac{dT}{dt})_{\max}$ | Approx. Δt_1 sec | $T_{\max}^{\circ R}$ | Approx. Δt_2 sec | g_{\max} | TERMINAL CONDITION |
|------------------|---------------------|-------------|-------|--------------------------|-----------------------------|----------------------|-----------------------------|------------|-----------------------|
| 8 | 0.01 | 2 | 0.01 | 0.119 | 60 | 6000 | -10 | 1.3 | EXIT |
| | | 2 | 0.03 | 0.0889 | 70 | 5500 | -40 | | |
| | | 4 | 0.01 | 0.105 | 55 | 5490 | -10 | | |
| | | 4 | 0.03 | 0.0735 | 70 | 4840 | -50 | | |
| | | 6 | 0.04 | 0.0548 | 75 | 4090 | -65 | | |
| 8.25 | 0.01 | 2 | 0.01 | 0.142 | 55 | 6690 | 5 | 2.8 | EXIT |
| | | 2 | 0.03 | 0.114 | 60 | 6320 | -25 | | |
| | | 4 | 0.01 | 0.128 | 60 | 6130 | -5 | | |
| | | 4 | 0.03 | 0.0964 | 70 | 5640 | -35 | | |
| | | 6 | 0.04 | 0.0744 | 75 | 4940 | -50 | | |
| 8.5 | 0.01 | 2 | 0.01 | 0.165 | 55 | 7200 | 30 | 7.6 | IMPACT |
| | | 2 | 0.03 | 0.142 | 45 | 6780 | 15 | | |
| | | 4 | 0.01 | 0.151 | 55 | 6540 | 20 | | |
| | | 4 | 0.03 | 0.121 | 55 | 6040 | 5 | | |
| | | 6 | 0.04 | 0.0959 | 60 | 5240 | -10 | | |
| 9 | 0.01 | 2 | 0.01 | 0.214 | 30 | 7630 | 20 | 18.1 | IMPACT |
| | | 4 | 0.01 | 0.196 | 30 | 7000 | 10 | | |
| | | 2 | 0.03 | 0.194 | 30 | 6950 | 5 | | |
| | | 4 | 0.03 | 0.164 | 25 | 6070 | 5 | | |
| | | 6 | 0.04 | 0.132 | 30 | 5060 | -5 | | |

"S" TRAJECTORIES

$$\Delta t_1 = [\text{Time at } T_{\max}] - [\text{Time at } (\frac{dT}{dt})_{\max}]$$

$$\Delta t_2 = [\text{Time at } g_{\max} - \text{Time at } T_{\max}]$$

TABLE IV

$$V = 1.3911$$

| $-\gamma_o$ deg. | $C_{D_o} \bar{S}/m$ | R' ft. | D ft. | $(\frac{dT}{dt})_{\max}$ | Approx. Δt_1 sec | $T_{\max}^{\circ R}$ 1st 2nd PEAK | Approx. Δt_2 sec | g_{\max} 1st 2nd PEAK | TERM- INAL CONDI- TION |
|------------------|---------------------|-------------|---------|--------------------------|-----------------------------|---|-----------------------------|-------------------------------|---------------------------------|
| 8 | 0.04 | 2 | 0.01 | 0.123 | 60 | 5650 4380 | -5 | 3.4 8.6 | IMPACT |
| | | 2 | 0.02 | 0.101 | 50 | 5420 4240 | -15 | | |
| | | 4 | 0.01 | 0.105 | 60 | 5170 4010 | -5 | | |
| | | 2 | 0.03 | 0.086 | 70 | 5080 4060 | -35 | | |
| | | 3 | 0.02 | 0.0920 | 60 | 5070 4000 | -25 | | |
| | | 4 | 0.03 | 0.0686 | 80 | 4460 3620 | -45 | | |
| 8.25 | 0.04 | 2 | 0.01 | 0.136 | 40 | 6040 | 80 | 7.2 | IMPACT |
| | | 2 | 0.02 | 0.121 | 40 | 5720 | 70 | | |
| | | 4 | 0.01 | 0.123 | 40 | 5500 | 80 | | |
| | | 3 | 0.02 | 0.110 | 50 | 5340 | 60 | | |
| | | 2 | 0.03 | 0.102 | 50 | 5300 | 50 | | |
| | | 4 | 0.03 | 0.0846 | 50 | 4620 | 50 | | |
| 8.5 | 0.04 | 2 | 0.01 | 0.160 | 40 | 6230 | 10 | 13.6 | IMPACT |
| | | 2 | 0.02 | 0.142 | 40 | 5810 | -5 | | |
| | | 4 | 0.01 | 0.142 | 30 | 5680 | 10 | | |
| | | 3 | 0.02 | 0.127 | 40 | 5420 | -5 | | |
| | | 2 | 0.03 | 0.122 | 40 | 5280 | -15 | | |
| | | 4 | 0.03 | 0.101 | 40 | 4560 | -15 | | |

TABLE V

$$V = 1.3088$$

| $-\gamma_o$ deg. | C_{D_o} | \bar{S}/m | R' ft. | D ft. | $(\frac{dT}{dt})_{\max}$ | Approx. Δt_1 sec | T_{\max} °R | Approx. Δt_2 sec | g_{\max} | TERMINAL CONDITION |
|------------------|-----------|-------------|-------------|-------|--------------------------|-----------------------------|---------------|-----------------------------|------------|-----------------------|
| 7.5 | 0.01 | | 2 | 0.01 | 0.0995 | 60 | 5770 | -5 | 1.3 | EXIT |
| | | | 2 | 0.03 | 0.0759 | 85 | 5330 | -40 | | |
| | | | 4 | 0.01 | 0.0889 | 70 | 5280 | -10 | | |
| | | | 4 | 0.03 | 0.0627 | 75 | 4710 | -50 | | |
| | | | 6 | 0.04 | 0.0470 | 90 | 4000 | -70 | | |
| 8 | 0.01 | | 2 | 0.01 | 0.144 | 55 | 6920 | 35 | 8.9 | IMPACT |
| | | | 2 | 0.03 | 0.126 | 45 | 6460 | 20 | | |
| | | | 4 | 0.01 | 0.132 | 45 | 6340 | 35 | | |
| | | | 4 | 0.03 | 0.107 | 45 | 5730 | 15 | | |
| | | | 6 | 0.04 | 0.0842 | 60 | 4920 | -5 | | |
| 9 | 0.01 | | 2 | 0.01 | 0.229 | 25 | 7500 | 20 | 23.6 | IMPACT |
| | | | 4 | 0.01 | 0.216 | 25 | 6820 | 20 | | |
| | | | 2 | 0.03 | 0.202 | 30 | 6430 | 5 | | |
| | | | 4 | 0.03 | 0.175 | 35 | 5590 | 5 | | |
| | | | 6 | 0.04 | 0.137 | 30 | 4520 | -5 | | |

TABLE VI

$$V = 1.3088$$

| $-\gamma_0$ deg. | $C_{D_0} \bar{S}/m$ | R' ft. | D ft. | $(\frac{dT}{dt})_{\max}$ | Approx. Δt_1 sec | T_{\max} °R | Approx. Δt_2 sec | g_{\max} | TERMINAL CONDITION |
|------------------|---------------------|-------------|-------|--------------------------|-----------------------------|---------------|-----------------------------|------------|-----------------------|
| 7 | 0.04 | 2 | 0.01 | 0.0610 | 70 | 4180 | -25 | 1.0 | EXIT |
| | | 3 | 0.01 | 0.0550 | 50 | 3920 | -25 | | |
| | | 4 | 0.01 | 0.0520 | 60 | 3740 | -35 | | |
| | | 2 | 0.02 | 0.0466 | 80 | 3710 | -55 | | |
| | | 5 | 0.01 | 0.0494 | 60 | 3610 | -35 | | |
| | | 3 | 0.02 | 0.0407 | 70 | 3410 | -55 | | |
| | | 2 | 0.03 | 0.0365 | 90 | 3260 | -75 | | |
| | | 2 | 0.04 | 0.0297 | 90 | 2900 | -75 | | |
| | | 4 | 0.03 | 0.0282 | 90 | 2760 | -75 | | |
| 7.5 | 0.04 | 2 | 0.01 | 0.0808 | 80 | 5430 | -5 | 3.3* | IMPACT |
| | | 2 | 0.02 | 0.0868 | 60 | 5180 | -25 | | |
| | | 4 | 0.01 | 0.0792 | 40 | 4950 | -5 | | |
| | | 2 | 0.03 | 0.0729 | 80 | 4850 | -45 | | |
| | | 3 | 0.02 | 0.0789 | 60 | 4850 | -25 | | |
| | | 4 | 0.03 | 0.0584 | 90 | 4250 | -65 | | |
| 8 | 0.04 | 2 | 0.01 | 0.139 | 30 | 5940 | 20 | 13.5 | IMPACT |
| | | 2 | 0.02 | 0.124 | 30 | 5480 | 10 | | |
| | | 4 | 0.01 | 0.127 | 40 | 5370 | 10 | | |
| | | 3 | 0.02 | 0.114 | 40 | 5080 | -5 | | |
| | | 2 | 0.03 | 0.106 | 40 | 4960 | -5 | | |
| | | 4 | 0.03 | 0.0856 | 40 | 4240 | -15 | | |

* second $g_{\max} = 7.7$

TABLE VII

$V = 1.3911 \quad \alpha = 0 \quad C_{D_0} \bar{S}/m = 0.024$

| $-\gamma_0$ deg | R' ft. | D ft. | $(\frac{dT}{dt})_{\max}$ | Approx. Δt_1 sec | T_{\max} °R | Approx. Δt_2 sec | g_{\max} | TERMINAL CONDITION |
|-----------------|--------|-------|--------------------------|--------------------------|---------------|--------------------------|------------|--------------------|
| 8 | 2 | 0.01 | 0.118 | 55 | 5840 | 0 | 2.0 | EXIT |
| | 6 | 0.01 | 0.0964 | 50 | 5050 | -10 | | |
| | 2 | 0.05 | 0.0653 | 80 | 4660 | -55 | | |
| | 4 | 0.03 | 0.0702 | 65 | 4650 | -40 | | |
| | 6 | 0.05 | 0.0446 | 90 | 3620 | -75 | | |
| 9 | 2 | 0.01 | 0.210 | 30 | 6930 | 10 | 20.3 | IMPACT |
| | 6 | 0.01 | 0.180 | 25 | 5920 | 10 | | |
| | 4 | 0.03 | 0.141 | 30 | 4990 | -5 | | |
| | 2 | 0.05 | 0.132 | 30 | 4790 | -10 | | |
| | 6 | 0.05 | 0.0914 | 35 | 3580 | -15 | | |
| 12 | 2 | 0.01 | 0.450 | 10 | 7370 | 0 | 53.8 | IMPACT |
| | 6 | 0.01 | 0.376 | 10 | 6060 | 0 | | |
| | 2 | 0.03 | 0.316 | 10 | 5260 | -5 | | |
| | 4 | 0.03 | 0.256 | 15 | 4380 | -5 | | |
| | 2 | 0.05 | 0.232 | 15 | 4060 | -10 | | |
| | 6 | 0.05 | 0.157 | 15 | 2960 | -10 | | |

"B" Trajectories

$\Delta t_1 = [\text{Time at } T_{\max}] - [\text{Time at } (\frac{dT}{dt})_{\max}]$

$\Delta t_2 = [\text{Time at } g_{\max}] - [\text{Time at } T_{\max}]$

TABLE VIII

$$V = 1.3911 \quad a = 0$$

| $-\gamma_o$ deg | C_{D_o} | \bar{S}/m | R' ft. | D ft. | $(\frac{dT}{dt})_{\max}$ | Approx. Δt_1 sec | T_{\max} °R | Approx. Δt_2 sec | g_{\max} | TERMINAL CONDITION |
|-----------------|-----------|-------------|-------------|-------|--------------------------|-----------------------------|---------------|-----------------------------|------------|-----------------------|
| 8 | 0.008 | | 2 | 0.01 | 0.119 | 60 | 6010 | -10 | 0.7 | EXIT |
| | | | 6 | 0.01 | 0.0975 | 55 | 5200 | -15 | | |
| | | | 2 | 0.05 | 0.0687 | 75 | 4840 | -60 | | |
| | | | 4 | 0.03 | 0.0734 | 70 | 4830 | -50 | | |
| | | | 6 | 0.05 | 0.0475 | 80 | 3740 | -70 | | |
| 9 | 0.008 | | 2 | 0.01 | 0.215 | 35 | 7870 | 15 | 17.1 | IMPACT |
| | | | 6 | 0.01 | 0.190 | 30 | 6830 | 12 | | |
| | | | 4 | 0.03 | 0.172 | 30 | 6340 | 0 | | |
| | | | 2 | 0.05 | 0.163 | 35 | 6320 | -5 | | |
| | | | 6 | 0.05 | 0.121 | 35 | 4890 | -10 | | |
| 9 | 0.012 | | 2 | 0.01 | 0.215 | 30 | 7520 | 15 | 18.3 | IMPACT |
| | | | 6 | 0.01 | 0.189 | 25 | 6500 | 10 | | |
| | | | 4 | 0.03 | 0.162 | 30 | 5840 | 0 | | |
| | | | 2 | 0.05 | 0.153 | 35 | 5740 | -5 | | |
| | | | 5 | 0.04 | 0.132 | 30 | 5040 | -5 | | |
| | | | 6 | 0.05 | 0.110 | 35 | 4380 | -15 | | |
| 9 | 0.016 | | 2 | 0.01 | 0.212 | >20 | >7170 | <20 | 19.2 | IMPACT |
| | | | 4 | 0.01 | 0.197 | 30 | 6640 | 10 | | |
| | | | 3 | 0.02 | 0.189 | 25 | 6420 | 5 | | |
| | | | 2 | 0.03 | 0.182 | 25 | 6340 | 0 | | |
| | | | 6 | 0.01 | 0.184 | 25 | 6270 | 10 | | |
| | | | 3.5 | 0.03 | 0.159 | 30 | 5650 | -5 | | |
| | | | 4 | 0.03 | 0.153 | >25 | >5380 | <5 | | |
| | | | 2 | 0.05 | 0.145 | 30 | 5340 | -5 | | |
| | | | 6 | 0.03 | 0.137 | 30 | 5010 | -5 | | |
| | | | 6 | 0.05 | 0.102 | 35 | 4040 | -15 | | |

TABLE IX

$$V = 1.3911 \quad C_{D_0} \bar{S}/m = 0.024$$

| $-\gamma_0$ deg | α | R' ft. | D ft. | $(\frac{dT}{dt})_{\max}$ | Approx. Δt_1 sec | $T_{\max}^{\circ R}$ | Approx. Δt_2 sec | g_{\max} | TERMINAL CONDITION |
|-----------------|----------|--------|-------|--------------------------|--------------------------|----------------------|--------------------------|------------|--------------------|
| 8 | 5 | 2 | 0.01 | 0.118 | 55 | 5760 | -5 | 1.8 | EXIT |
| | | 6 | 0.01 | 0.0958 | 50 | 4970 | -10 | | |
| | | 4 | 0.03 | 0.0692 | 65 | 4490 | -45 | | |
| | | 2 | 0.05 | 0.640 | 80 | 4460 | -60 | | |
| | | 6 | 0.05 | 0.0434 | 90 | 3430 | -70 | | |
| 9 | 5 | 2 | 0.01 | 0.209 | 30 | 6860 | 5 | 15.0 | IMPACT |
| | | 6 | 0.01 | 0.179 | 25 | 5860 | 5 | | |
| | | 4 | 0.03 | 0.138 | 35 | 4980 | -15 | | |
| | | 2 | 0.05 | 0.128 | 40 | 4830 | -20 | | |
| | | 6 | 0.05 | 0.0889 | 45 | 3640 | -30 | | |
| 8 | 10 | 2 | 0.01 | 0.117 | 50 | 5700 | -5 | 1.6 | EXIT |
| | | 6 | 0.01 | 0.955 | 50 | 4900 | -15 | | |
| | | 4 | 0.03 | 0.683 | 65 | 4360 | -45 | | |
| | | 2 | 0.05 | 0.0628 | 70 | 4300 | -55 | | |
| | | 6 | 0.05 | 0.0426 | 90 | 3280 | -75 | | |
| 9 | 10 | 2 | 0.01 | 0.205 | 25 | 6780* | 5 | 12.2 | IMPACT |
| | | 6 | 0.01 | 0.179 | 25 | 5790 | 0 | | |
| | | 4 | 0.03 | 0.135 | 35 | 4930 | -20 | | |
| | | 2 | 0.05 | 0.125 | 40 | 4800 | -30 | | |
| | | 6 | 0.05 | 0.0862 | 65 | 3650 | -50 | | |

*2nd peak $T_{\max} = 3440$

TABLE X

$V = 1.3911 \quad \alpha = 30$

| $-\gamma_o$ deg | $D_o \bar{S}/m$ | R' ft. | ft. | $(\frac{dT}{dt})_{\max}$ | Approx. Δt_1 sec | T_{\max} °R | Approx. Δt_2 sec | g_{\max} | TERMINAL CONDITION |
|-----------------|-----------------|----------|------|--------------------------|-----------------------------|---------------|-----------------------------|------------|-----------------------|
| 8 | 0.024 | 2 | 0.01 | 0.114 | 40 | 5480 | -10 | 1.6 | EXIT |
| | | 4 | 0.01 | 0.103 | 45 | 4970 | -15 | | |
| | | 3 | 0.02 | 0.0872 | 55 | 4720 | -30 | | |
| | | 6 | 0.01 | 0.0938 | 50 | 4670 | -15 | | |
| | | 2 | 0.03 | 0.0807 | 55 | 4630 | -40 | | |
| | | 3.5 | 0.03 | 0.0678 | 65 | 4090 | -50 | | |
| | | 4 | 0.03 | 0.0648 | 65 | 3980 | -50 | | |
| | | 2 | 0.05 | 0.0590 | 80 | 3850 | -65 | | |
| | | 6 | 0.03 | 0.564 | 65 | 3620 | -50 | | |
| | | 6 | 0.05 | 0.0393 | 90 | 2890 | -80 | | |
| 9 | 0.024 | 2 | 0.01 | 0.205 | 25 | 6440 | 0 | 8.7 | EXIT |
| | | 4 | 0.02 | 0.152 | 30 | 5140 | -15 | | |
| | | 2 | 0.04 | 0.129 | 40 | 4800 | -30 | | |
| | | 6 | 0.02 | 0.136 | 30 | 4730 | -20 | | |
| | | 2 | 0.05 | 0.112 | 50 | 4390 | -40 | | |
| | | 6 | 0.03 | 0.108 | 45 | 4130 | -35 | | |
| | | 4.5 | 0.05 | 0.0844 | 60 | 3570 | -40 | | |

TABLE XI

$V = 1.3911 \quad \alpha = 30$

| | | | | FIRST PEAK | | | | SECOND PEAK | | | | | |
|--------------------|-----------|-------------|-------------|--------------------|-------------------------|-----------------------------|-------------------|-----------------------------|-------------------------|-----------------------------|-----------|-----------------------------|---------------------------------|
| $-\gamma_o$ deg | C_{D_o} | \bar{S}/m | R' ft. | D ft | $(\frac{dT}{dt})_{max}$ | Appx Δt_1 sec | $T_{max} R^o$ | Appx Δt_2 sec | $(\frac{dT}{dt})_{max}$ | Appx Δt_1 sec | T_{max} | Appx Δt_2 sec | TERMIN- AL CONDI- TION |
| 10 | 0.024 | | 2 | 0.01 | 0.287 | 20 | 6740 | 0 | 0.0818 | 20 | 4230 | -5 | IMPACT |
| | | | 6 | 0.01 | 0.238 | 15 | 5640 | -5 | 0.0628 | 25 | 3490 | -10 | |
| | | | 4 | 0.02 | 0.206 | 25 | 5160 | -15 | 0.0434 | 25 | 3290 | -15 | |
| | | | 6 | 0.02 | 0.183 | 25 | 4720 | -15 | 0.0373 | 25 | 3070 | -15 | |
| | | | 2 | 0.04 | 0.172 | 35 | 4700 | -25 | 0.0308 | 35 | 3350 | -25 | |
| | | | 4 | 0.03 | 0.164 | 35 | 4460 | -25 | 0.0304 | 35 | 3100 | -25 | |
| | | | 2 | 0.05 | 0.149 | 45 | 4250 | -35 | 0.0248 | 35 | 3280 | -25 | |
| | | | 6 | 0.03 | 0.144 | 35 | 4040 | -25 | 0.0257 | 35 | 2920 | -25 | |
| | | | 4.5 | 0.05 | 0.112 | 45 | 3440 | -35 | 0.0178 | 35 | 2900 | -25 | |
| | | | 6 | 0.05 | 0.100 | 45 | 3180 | -35 | 0.0158 | 35 | 3100 | -25 | |
| | | | | $g_{max}^1 = 17.0$ | $g_{max}^2 = 8.6$ | $g_{max}^3 = 3.4$ | $g_{max}^4 = 1.2$ | | | | | | |

| | | | | | | | | | | | | | |
|----|-------|--|-----|--------------------|-------------------|-------------------|------|-----|--------|----|-------|----|--------|
| 12 | 0.024 | | 4 | 0.02 | 0.288 | 15 | 4990 | -10 | 0.0178 | 20 | 2760 | -5 | IMPACT |
| | | | 6 | 0.02 | 0.254 | 20 | 4530 | -10 | 0.0146 | 20 | 2640 | -5 | |
| | | | 2 | 0.04 | 0.235 | 20 | 4400 | -15 | 0.0105 | 20 | 3060 | -5 | |
| | | | 6 | 0.03 | 0.196 | 20 | 3770 | -15 | 0.0089 | 15 | 2690 | -5 | |
| | | | 4.5 | 0.05 | 0.151 | 30 | 3150 | -25 | 0.0063 | 15 | >2690 | -5 | |
| | | | | $g_{max}^1 = 34.1$ | $g_{max}^2 = 9.5$ | $g_{max}^3 = 1.8$ | | | | | | | |

TABLE XII

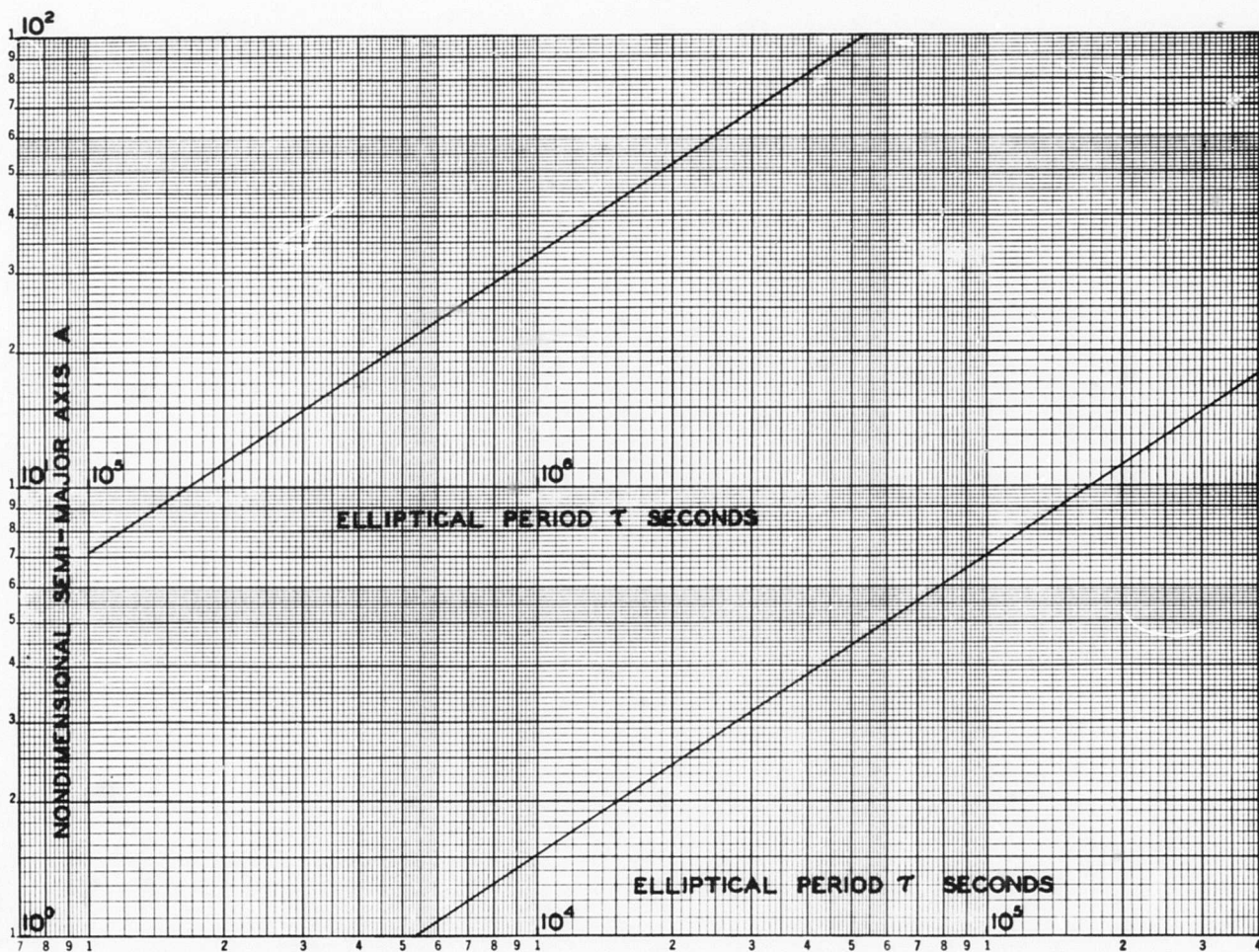


FIG. 1 MAJOR AXIS & PERIOD OF KEPLERIAN ELLIPSE

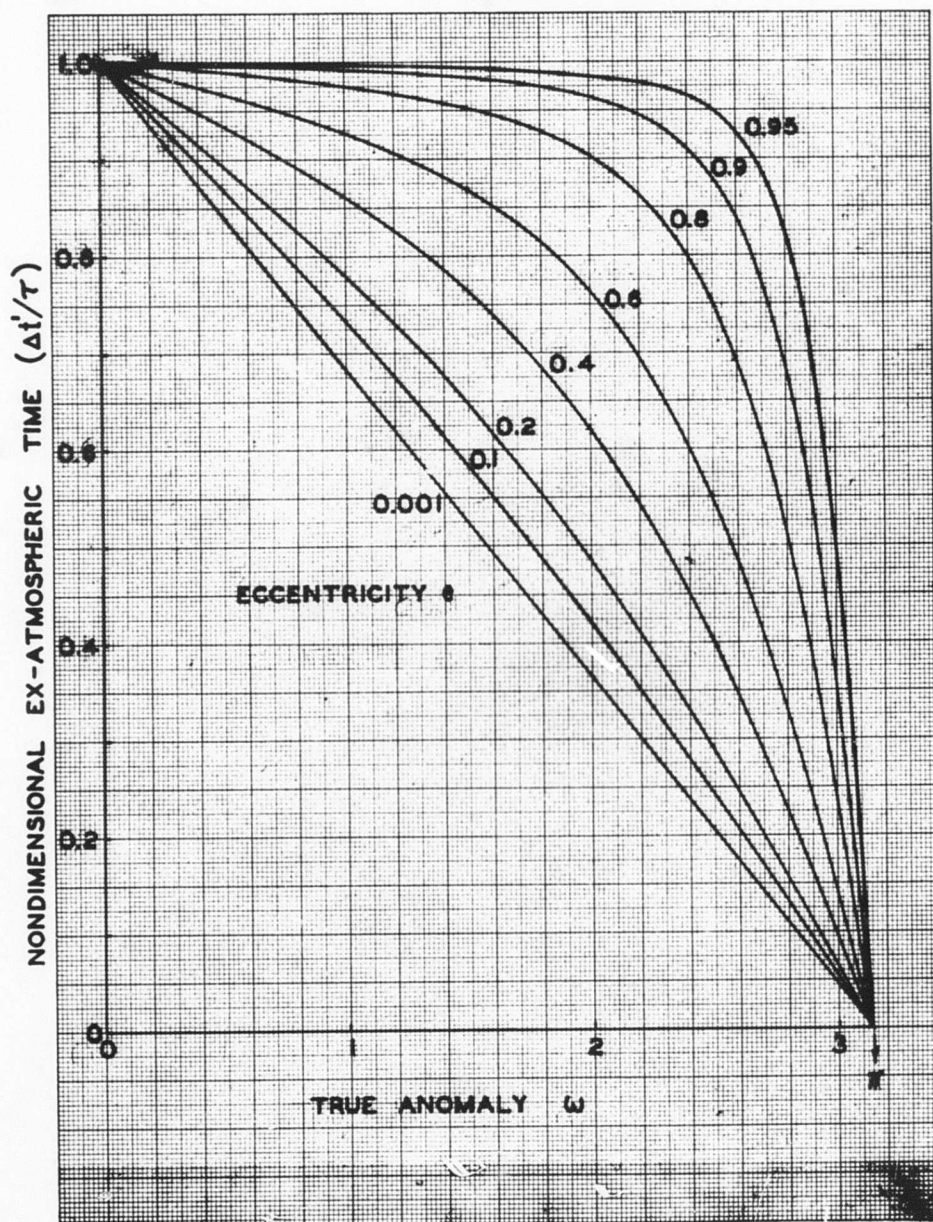


FIG. 2 EX-ATMOSPHERIC FLIGHT TIME IN TERMS OF EXIT CONDITIONS

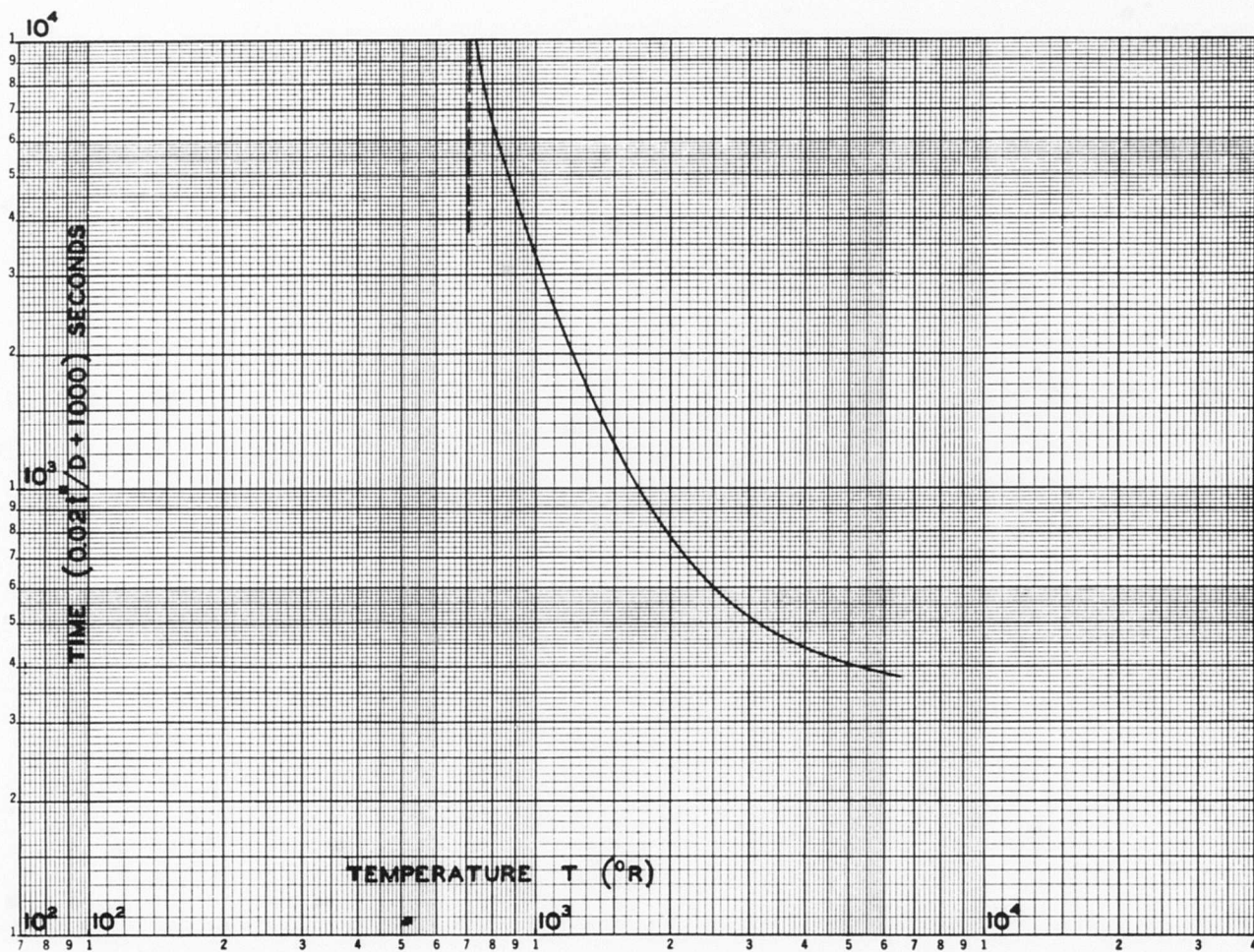


FIG. 3 REENTRY TEMPERATURE AND EX-ATMOSPHERIC FLIGHT TIME

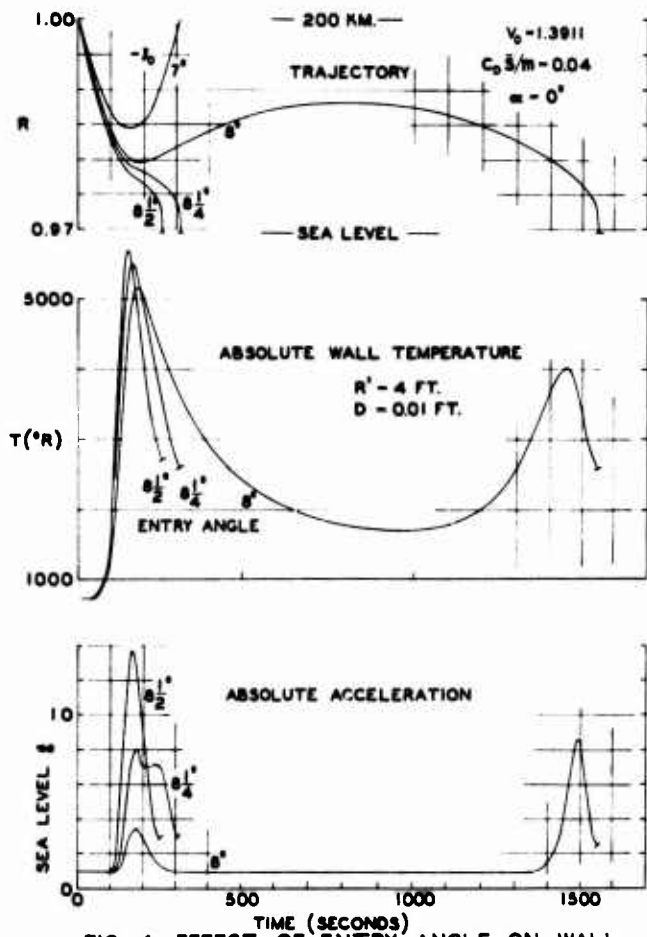


FIG. 4 EFFECT OF ENTRY ANGLE ON WALL TEMPERATURE AND DECELERATION

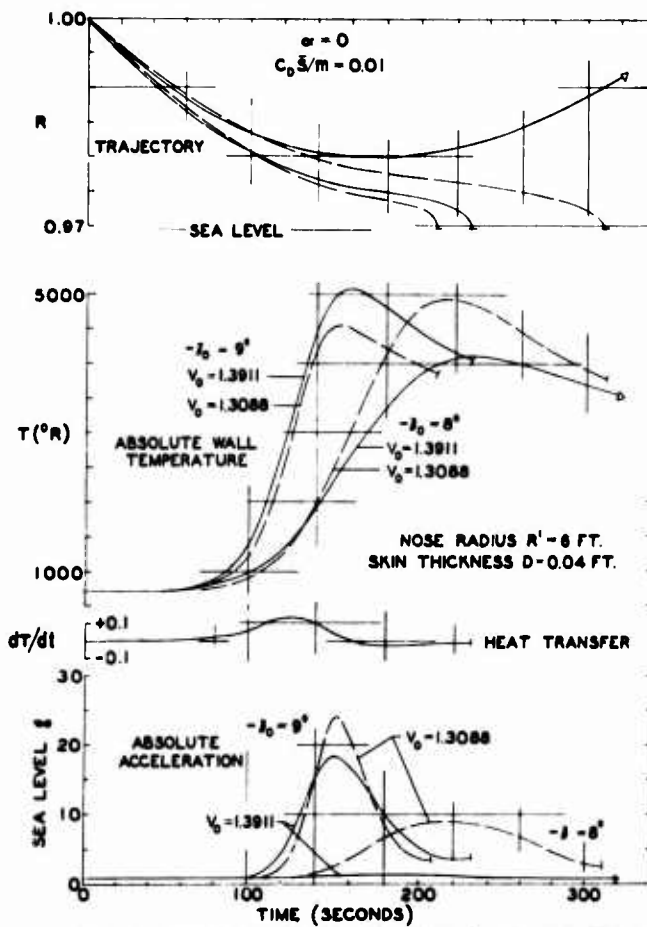


FIG. 5 EFFECT OF ENTRY VELOCITY ON WALL TEMPERATURE AND DECELERATION

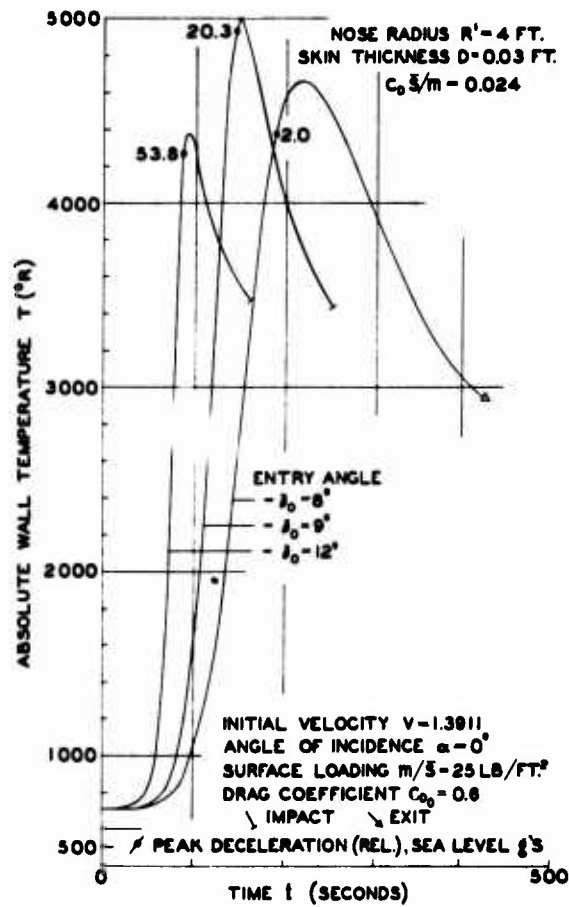


FIG. 6 ALLEVIATING EFFECT OF STEEP ENTRY ON WALL TEMPERATURE

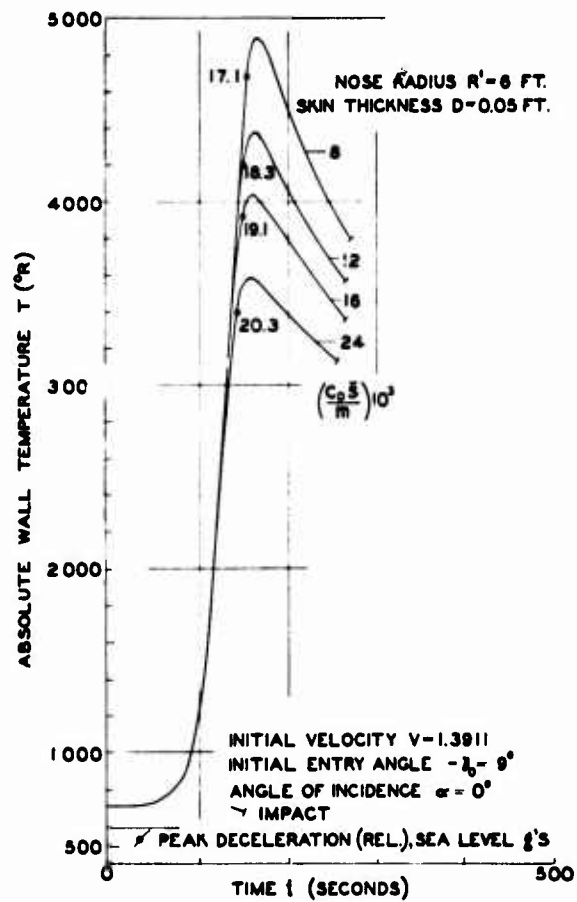


FIG. 7 EFFECT OF SURFACE LOADING $m/C_D \dot{s}$ ON WALL TEMPERATURE

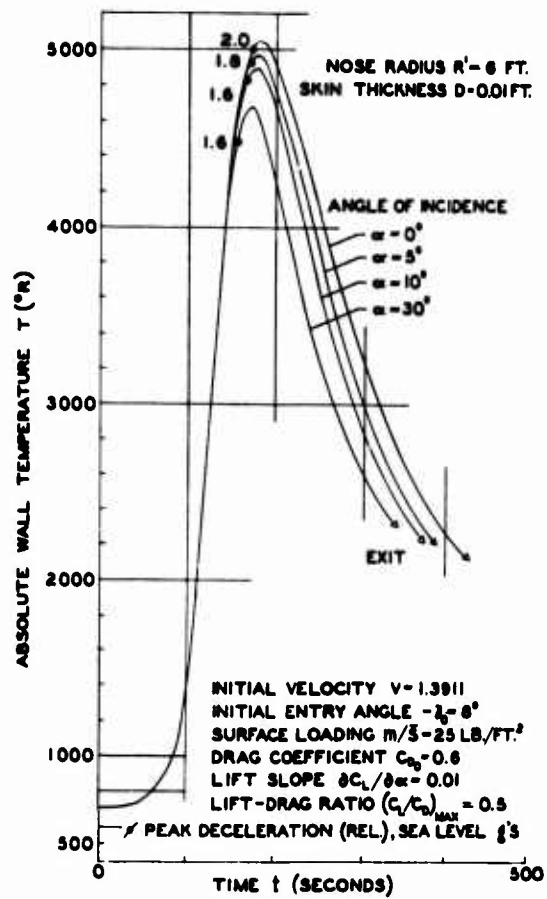


FIG. 8 EFFECT OF CONSTANT LIFT ON WALL TEMPERATURE

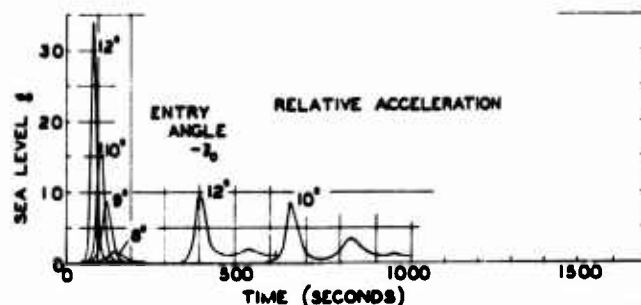
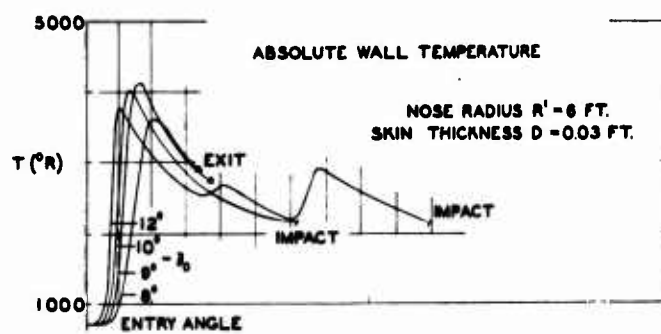
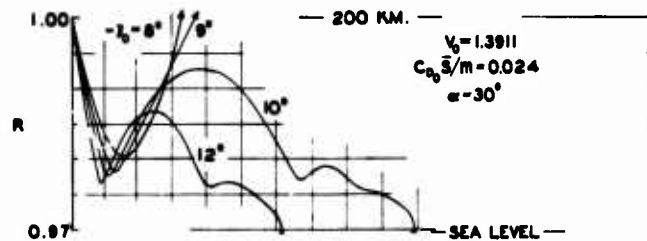
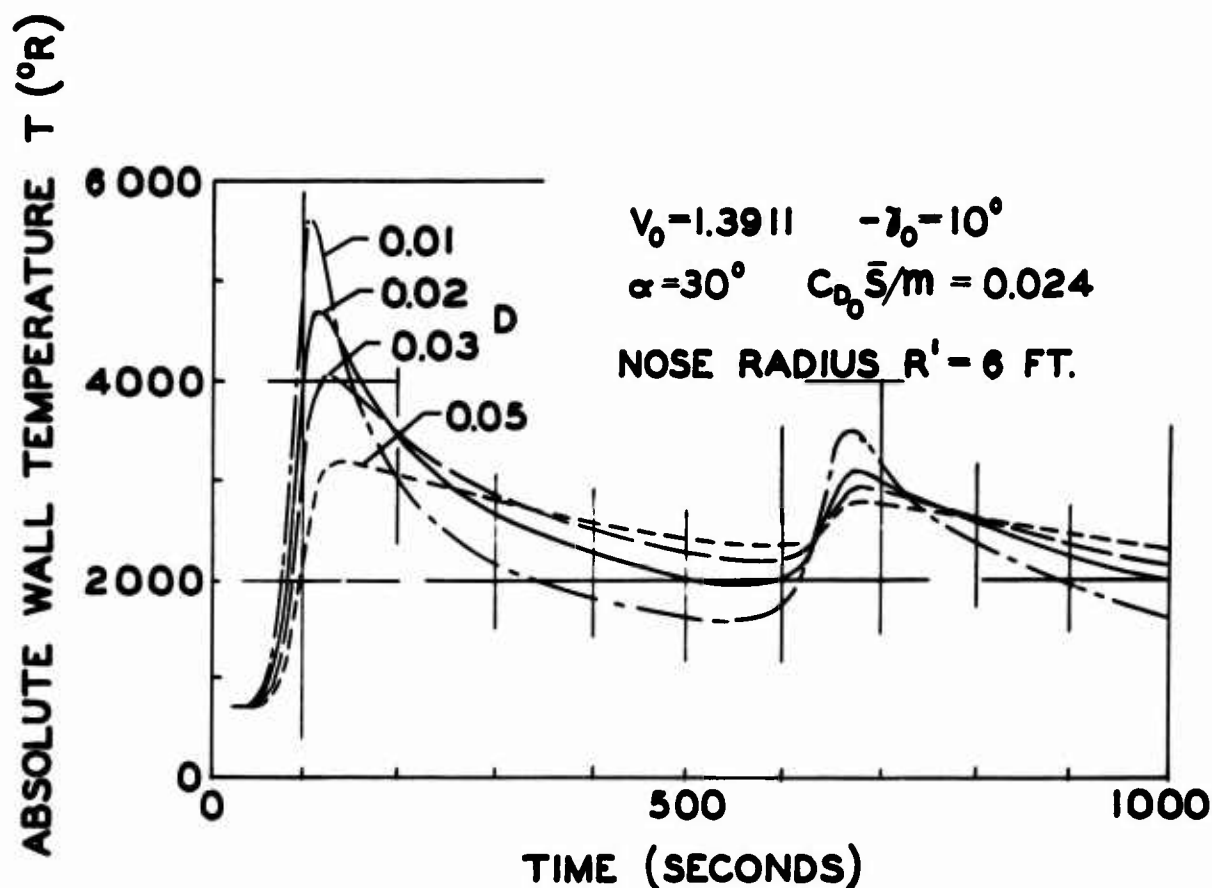
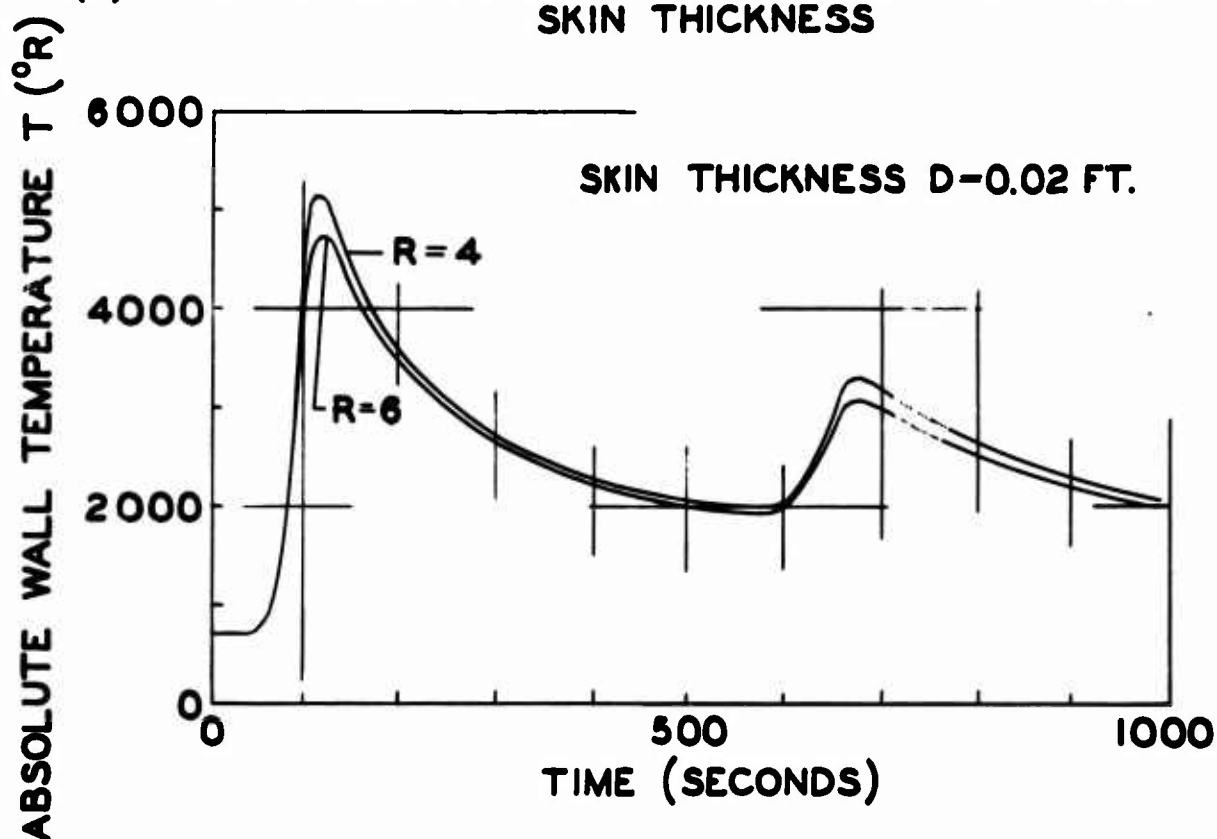


FIG. 9 EFFECT OF ENTRY ANGLE AT MAXIMUM LIFT ON DECELERATION AND TEMPERATURE



(a) THE EFFECT ON WALL TEMPERATURE OF NOSE SKIN THICKNESS



(b) THE EFFECT ON WALL TEMPERATURE OF NOSE RADIUS

FIG. 10 ENTRY AT MAXIMUM LIFT:
WALL TEMPERATURE - TIME HISTORIES

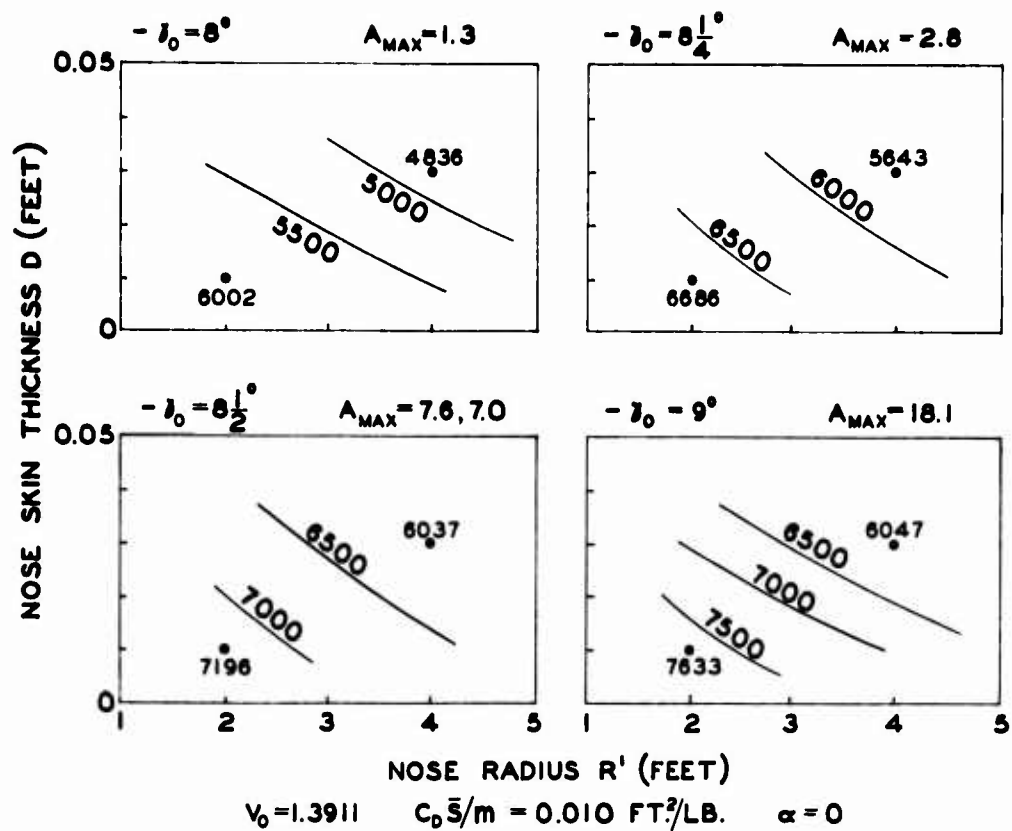


FIG. 11
NOSE GEOMETRY AND PEAK WALL TEMPERATURE:
EFFECT OF ENTRY ANGLE AT ZERO LIFT

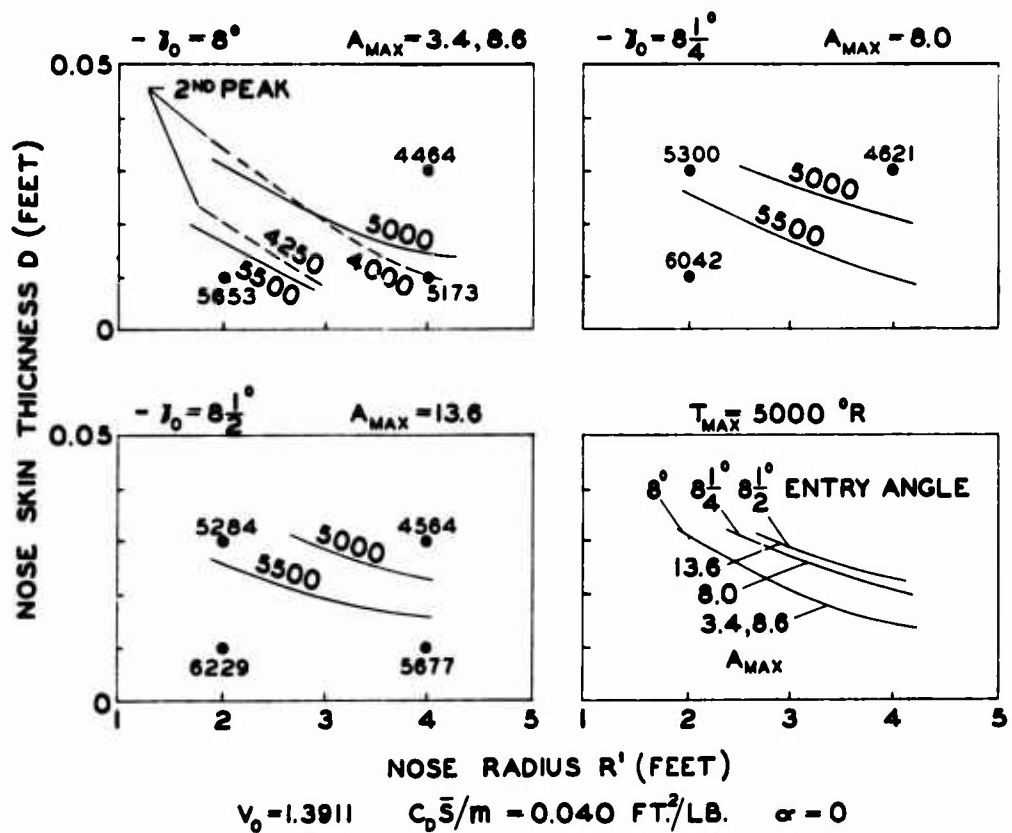


FIG. 12
NOSE GEOMETRY AND PEAK WALL TEMPERATURE:
EFFECT OF ENTRY ANGLE AT ZERO LIFT

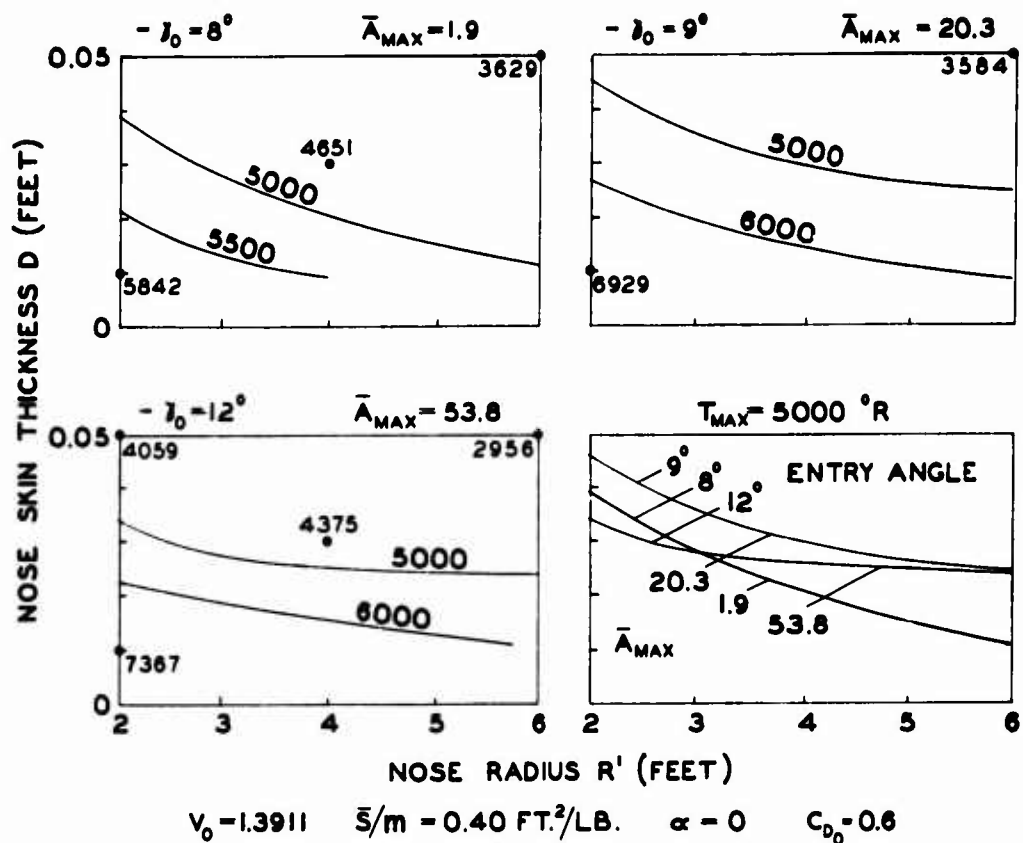


FIG. 13
NOSE GEOMETRY AND PEAK WALL TEMPERATURE:
EFFECT OF STEEP ENTRY AT ZERO LIFT

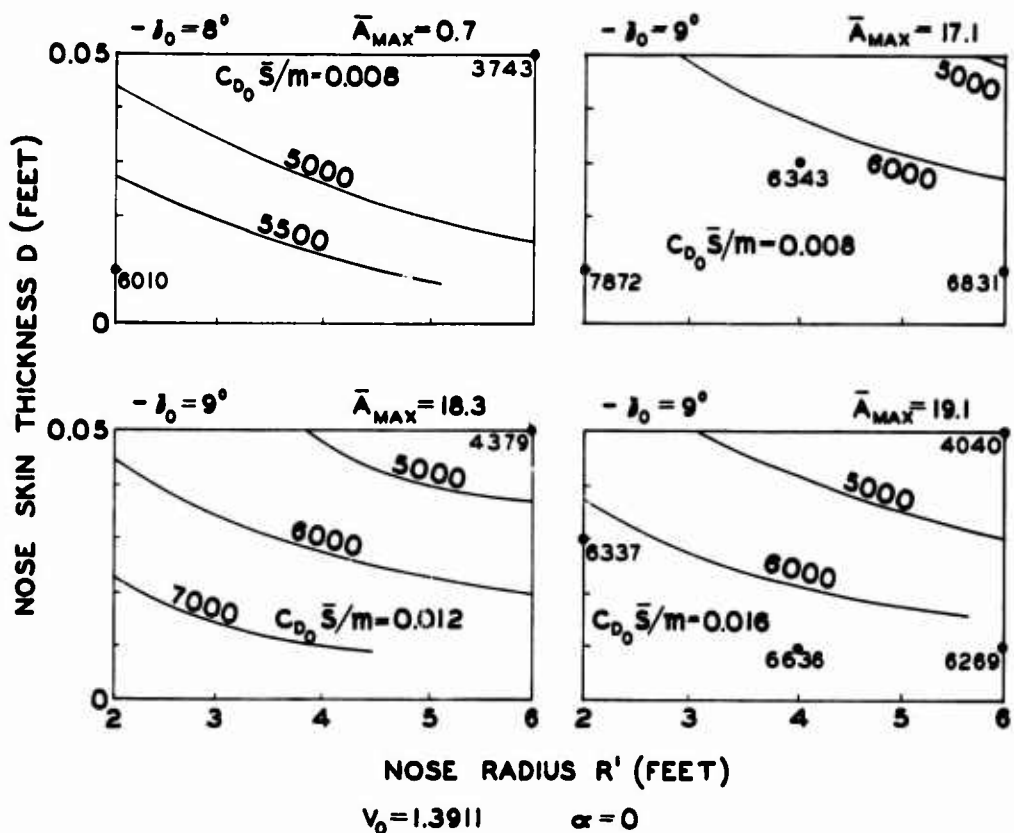


FIG. 14
NOSE GEOMETRY AND PEAK WALL TEMPERATURE:
EFFECT OF $m/C_D \bar{S}$ AT ZERO LIFT

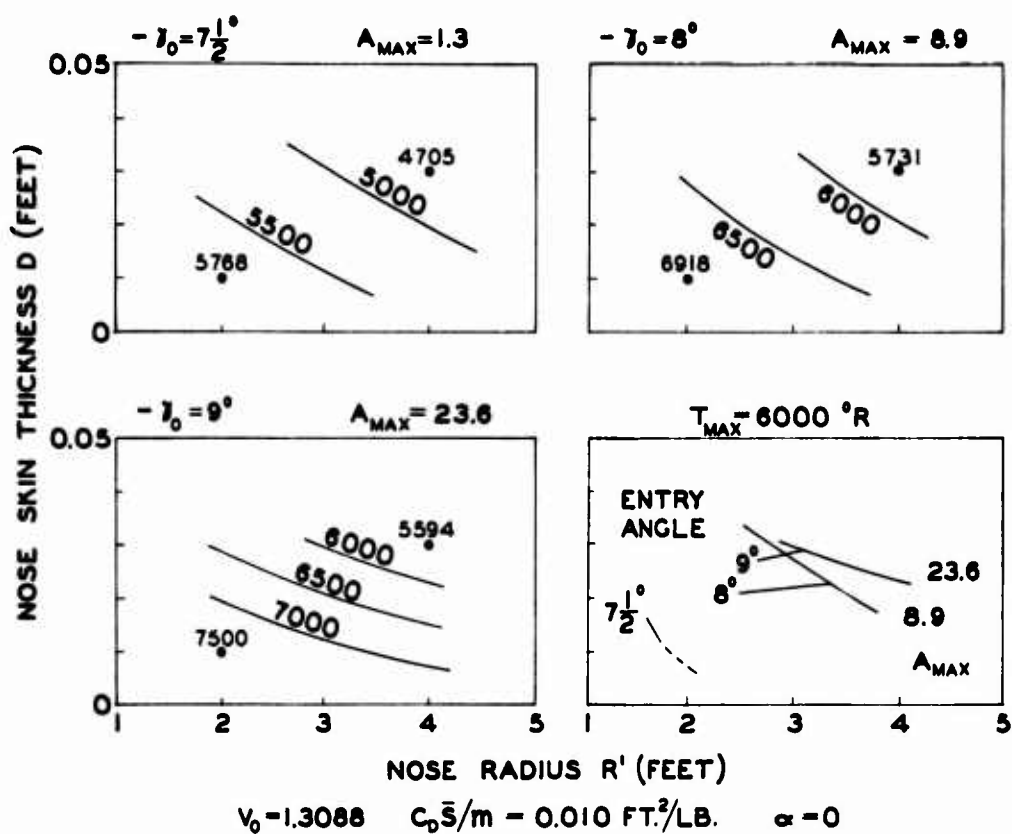


FIG. 15
NOSE GEOMETRY AND PEAK WALL TEMPERATURE:
EFFECT OF ENTRY ANGLE AT ZERO LIFT

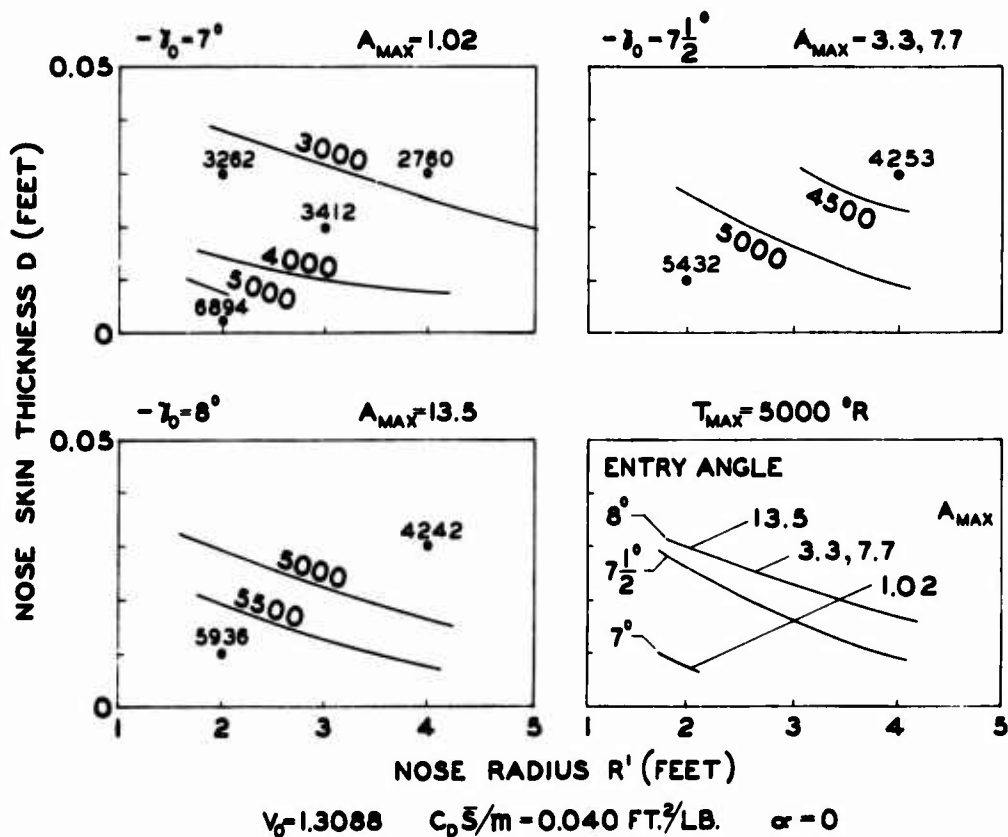


FIG. 16
NOSE GEOMETRY AND PEAK WALL TEMPERATURE:
EFFECT OF ENTRY ANGLE AT ZERO LIFT

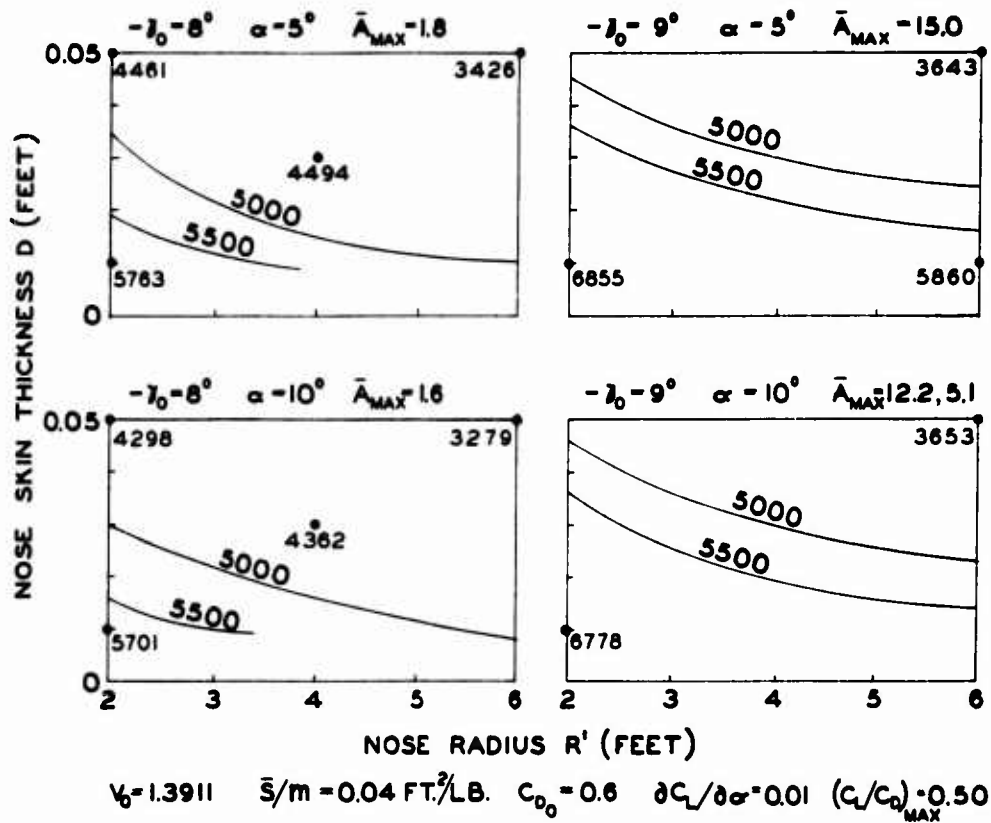


FIG. 17
NOSE GEOMETRY AND PEAK WALL TEMPERATURE:
LOW LIFT ENTRY

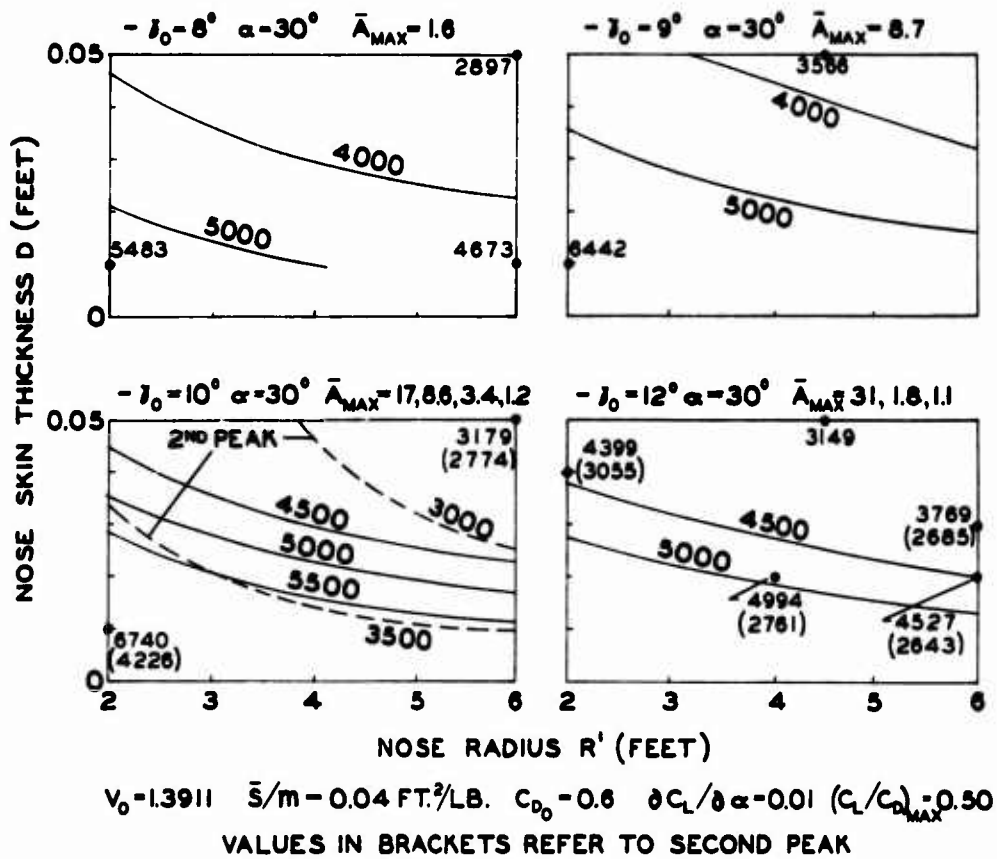


FIG. 18
NOSE GEOMETRY AND PEAK WALL TEMPERATURE:
MAXIMUM LIFT ENTRY